

EVALUATING FUTURE PROPULSION AND TECHNICAL REQUIREMENTS FOR UPPER STAGES

DRA

TASK 1 FINAL PRESENTATION

Contract NASW-2464

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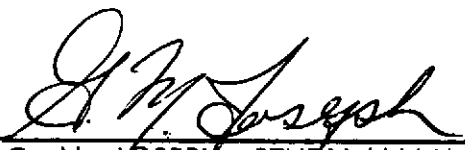
TASK 1 FINAL PRESENTATION

PB-AP-73-1A

**EVALUATING FUTURE PROPULSION
AND
TECHNICAL REQUIREMENTS FOR UPPER STAGES**

CONTRACT NASW-2464

SEPTEMBER 1973


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PREPARED FOR

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FOREWORD

This brochure documents the results of the work performed by the Chrysler Corporation Space Division, for the National Aeronautics and Space Administration, under Task Assignment 1 of Contract NASW-2464. All work conducted under this contract was performed under this single Task Assignment. Questions pertaining to this contract should be directed to the following persons:

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INTRODUCTION

In past years Chrysler has been conducting studies to aid the National Aeronautics and Space Administration in evaluating advanced technology requirements relating to chemical upper stages and the orbit-to-orbit stages. In the performance of these studies, Chrysler has utilized its upper stage sizing and costing computer program, CUSSER, to predict the effect of a given technology (e.g. high P_c engines) on the sizing and funding requirements of a stage designed to accomplish a specified mission.

These studies have proven very useful insofar as they went. However, it has become evident that a technology advancement should be examined in terms of its possible implication on a complete mission spectrum instead of just a single mission. Further, the importance of existing and alternate technologies should be considered concurrently in an analysis of the merits of a technology advancement. In recognition of this Chrysler undertook to develop an upper stage fleet optimization algorithm which would enable the determination of the cost optimum combination of existing and new stages (or technologies) to accomplish various mission spectrums. This tool, then, could be used to quantitatively assess the merits of a new stage or technology by running an analysis to determine what the total costs would be, with and without the new stage. It could also be used to determine the optimum size for a new stage considering an entire mission model and not just a primary mission.

INTRODUCTION

PRESENTATION OUTLINE

The presentation will be presented according to the following outline:

- Introduction - This section covers the background, objectives and the first task assignment of the study.
- Computer Program Description - The basic algorithm, upon which the computer program is based, is described along with a discussion of the pertinent cost equations.
- Study Data - Mission plans and stage data which were used during the study are presented in this section.
- Study Results - The optimum families of upper stages to accomplish the various mission plans studied are presented along with a discussion of sensitivities due to variable shuttle transportation-to-orbit costs.
- Conclusions - Study conclusions are presented in this section.

PRESENTATION OUTLINE

- INTRODUCTION
- COMPUTER PROGRAM DESCRIPTION
- STUDY DATA
- STUDY RESULTS
 - 52 MISSIONS PLAN
 - 24 MISSIONS PLAN
 - 19 MISSIONS PLAN
- CONCLUSIONS



STUDY OBJECTIVE

The objective of this study is essentially twofold:

- 1) To verify the efficacy of the Chrysler algorithm (and computer program) in evaluating technology alternatives; and
- 2) To conduct studies which will provide the NASA with a quantitative basis for decision making relative to future allocation of resources available for further development of propulsion technology.

STUDY OBJECTIVES

- TO VERIFY THE EFFICACY OF THE CHRYSLER ALGORITHM FOR EVALUATING TECHNOLOGY ALTERNATIVES
- CONDUCT STUDIES (BY TASK ASSIGNMENT) TO QUANTITATIVELY ASSESS THE VALUE OF ADVANCED PROPULSION TECHNOLOGY

TASK ASSIGNMENT 1

The first task assignment was to use the fleet assignment computer program to determine the optimum family of expendable upper stages to accomplish missions from 1970-1990. In addition, sensitivity studies were to be accomplished to show the effects of Shuttle transportation-to-orbit costs and the implications of omitting stages from consideration.

The results of these analyses were to serve two purposes:

- a) To enable the NASA to evaluate the algorithm; and
- b) to provide a baseline model propulsion cost (derived from families of existing stages) against which the merits of new technology stages can be quantitatively measured.

The basic contract for this study required individual studies to be accomplished on a task assignment basis.

TASK ASSIGNMENT 1

- ESTABLISH A "BASELINE" FAMILY COMPARISON OF EXISTING EXPENDABLE UPPER STAGES TO ACCOMPLISH MISSIONS FROM 1979 - 1990.
- PREPARE A PRESENTATION TO NASA PERSONNEL FOR DETAILED EVALUATION AND CRITICISM OF THE ALGORITHM AND RESULTS.



COMPUTER PROGRAM DESCRIPTION

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INPUT SUMMARY

A description of the input to a computer program is often a good point of departure for describing the program since it provides the reader with a subjective feel for the scope of the program and the validity or accuracy that may be expected. The accompanying chart summarizes the input used in the Chrysler Fleet Assignment Program according to the categories of Mission Data, Stage Data, Engine Data and Miscellaneous Data.

One of the more important features is that the program considers the relationship between mission requirements and stage capabilities, e.g.:

- First Flight date and stage availability;

- Number of mission burns and number of engine starts; and

- Mission duration and stage life.

Other important features include the ability to handle missions which have more than one payload and the ability to add a guidance module to stages which do not possess an integral GN&C capability. At present the program is constrained to the analysis of expendable stages only.

INPUT SUMMARY

MISSION DATA

NUMBER OF FLIGHTS
YEAR OF FIRST AND LAST FLIGHT
NUMBER OF MAIN BURNS
PAYLOAD FOR EACH BURN
 ΔV FOR EACH BURN
COAST TIME PRIOR TO EACH BURN

STAGE DATA

WEIGHT OF STAGE
WEIGHT OF PROPELLANT
WEIGHT OF STRUCTURE
DIAMETER
LENGTH
ENGINE IDENTIFICATION
NUMBER OF ENGINES
NUMBER OF STARTS
MAXIMUM LIFETIME
INTEGRAL GUIDANCE SYSTEM?
RDTE COST
TFU COST
PROPELLANT COST
LAUNCH, TRAINING, SUSTAINING
ENGINEERING COSTS

ENGINE DATA

THRUST
ISP
TFU COST
RDTE COST

MISCELLANEOUS DATA

COST CONSTRAINTS
VELOCITY LOSS EQUATION
CONSTRAINTS
GUIDANCE MODULE WEIGHT
GUIDANCE MODULE RDTE COST
GUIDANCE MODULE TFU COST
STAGES IN VEHICLE - LIMIT (3 MAX)
I/S WEIGHT PER SQUARE FOOT
LEARNING EXPONENTS
MAXIMUM VEHICLE LENGTH



VEHICLES SYNTHESIS

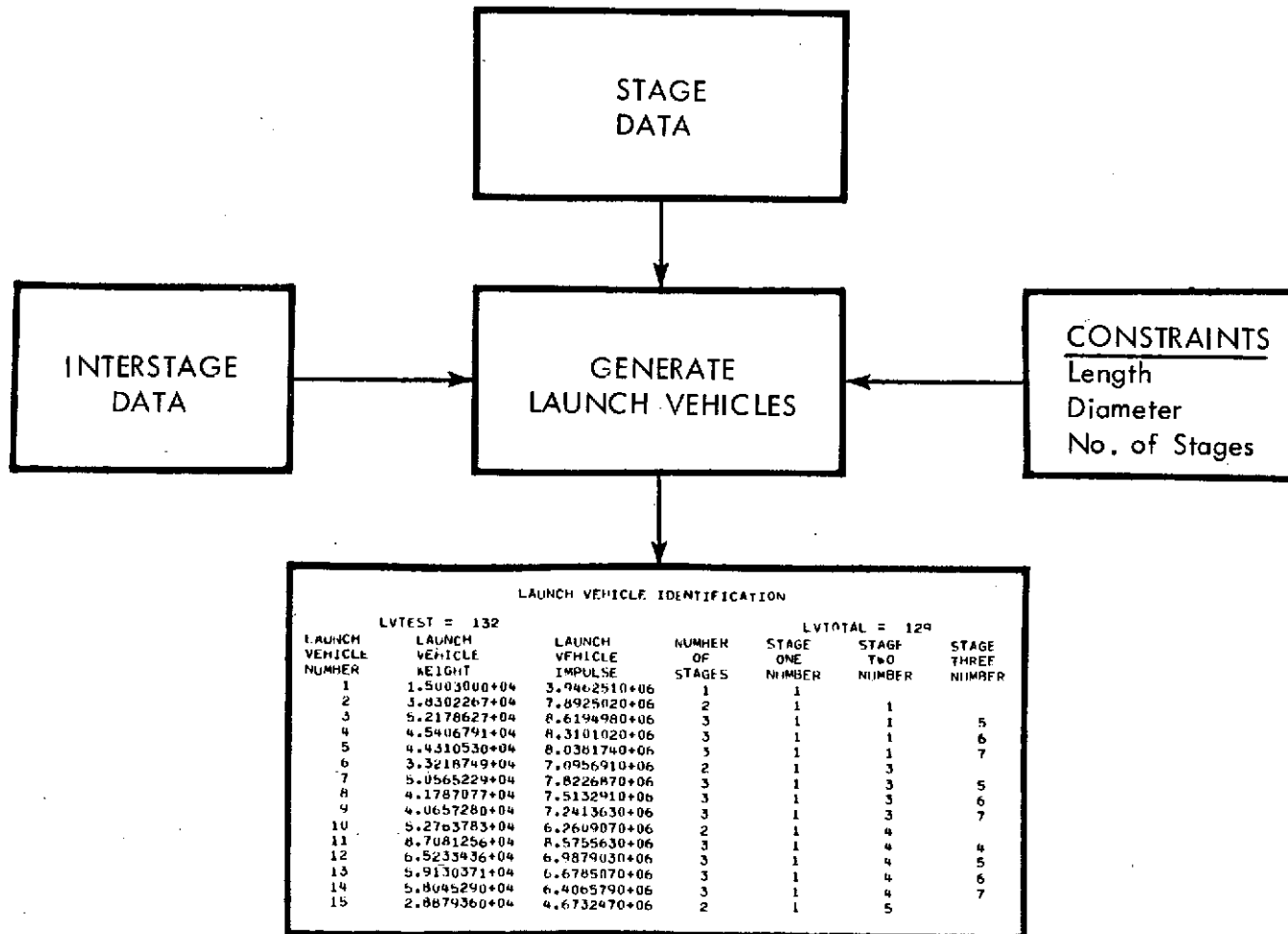
This and the following two charts summarize the algorithm upon which the computer program is based. The discussion is necessarily simplified in order to give a basic understanding of the approach.

The first step is the "invention" of vehicles from the stage alternatives which are input to the program. All possible configurations are examined except those which violate one of the programmed constraints. These constraints are:

- a) Stages are never put on top of smaller diameter stages; and
- b) The total vehicle length is not permitted to exceed an input maximum.

The user has the option of specifying the maximum number of stages in a vehicle, up to a limit of three. For multi-staged vehicles an interstage(s) is sized and included in the cost and performance computations. Key data on the vehicles which were synthesized are summarized in the program output.

VEHICLE SYNTHESIS



VEHICLE AND MISSION MATCHING

Every vehicle is tested against each mission by observing constraints of stage availability, life and number of starts as well as performance requirements. For each individual mission the vehicles which can accomplish that mission are ranked according to cost to accomplish that particular mission. Only the best twenty (20) vehicles are retained for future computational purposes in order to limit computer storage requirements and to reduce computation time. This is the first important simplifying assumption of the algorithm. The presumption is that the vehicle which will ultimately be in the final family will be one of these twenty vehicles. Based on the studies conducted to date this assumption appears to be safe.

VEHICLE AND MISSION MATCHING

LAUNCH VEHICLE IDENTIFICATION

LVTEST = 132 LVTOTAL = 120

LAUNCH VEHICLE NUMBER	LAUNCH VEHICLE WEIGHT	LAUNCH VEHICLE IMPULSE	NUMBER OF STAGES	STAGE ONE NUMBER	STAGE TWO NUMBER	STAGE THREE NUMBER
1	1.500300+04	3.9002510+06	1	1		
2	3.8302267+04	7.8925020+06	2	1	1	
3	5.2178627+04	8.6194980+06	3	1	1	5
4	4.5406791+04	8.3101020+06	3	1	1	6
5	4.4310530+04	8.0381740+06	3	1	1	7
6	3.3218749+04	7.0956910+06	2	1	3	
7	5.0565224+04	7.8226870+06	3	1	3	5
8	4.1787077+04	7.5132910+06	3	1	3	6
9	4.0657280+04	7.2413630+06	3	1	3	7
10	5.2703783+04	6.2609070+06	2	1	4	
11	8.7081256+04	8.5755630+06	3	1	4	4
12	6.5233436+04	6.9879030+06	3	1	4	5
13	5.9130371+04	6.6785070+06	3	1	4	6
14	5.8045290+04	6.4005790+06	3	1	4	7
15	2.8874360+04	4.6732470+06	2	1	5	

MISSION MODEL

CONSTRAINTS
Availability
Life
No. of Starts

TEST
VEHICLES & MISSIONS
AGAINST EACH OTHER

COST DATA

LAUNCH VEHICLE COST RANKING BY MISSION

RANK	MISSION NUMBER 1 COST VEHICLE	MISSION NUMBER 2 COST VEHICLE	MISSION NUMBER 3 COST VEHICLE	MISSION NUMBER 4 COST VEHICLE	MISSION NUMBER 5 COST VEHICLE
1	.1053324+03 122	.1003976+03 24	.1320800+03 45	.1099753+03 45	.1100997+03 89
2	.1107639+03 24	.1212376+03 129	.1747926+03 96	.1390830+03 96	.1104581+03 45
3	.1251040+03 129	.1669925+03 124	.1800694+03 46	.1417566+03 46	.1104970+03 80
4	.1584164+03 102	.1675796+03 26	.2040755+03 1	.1671445+03 1	.1235062+03 90
5	.1584262+03 39	.1706910+03 123	.2430099+03 24	.1930756+03 24	.1282959+03 81
6	.1602030+03 36	.1771247+03 25	.2635013+03 122	.1976852+03 122	.1329362+03 96
7	.1646645+03 37	.1805256+03 41	.2644072+03 2	.2070758+03 2	.1436741+03 66
8	.1691525+03 103		.2690263+03 44	.2106981+03 50	.1487030+03 46
9	.1760458+03 124		.2921146+03 117	.2142037+03 49	.1775674+03 87
10	.1791533+03 97		.3125442+03 118	.2154767+03 69	.1780278+03 1

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FAMILY SELECTION

After the vehicle/mission matrix has been completed, the development of the optimum family is initiated as follows:

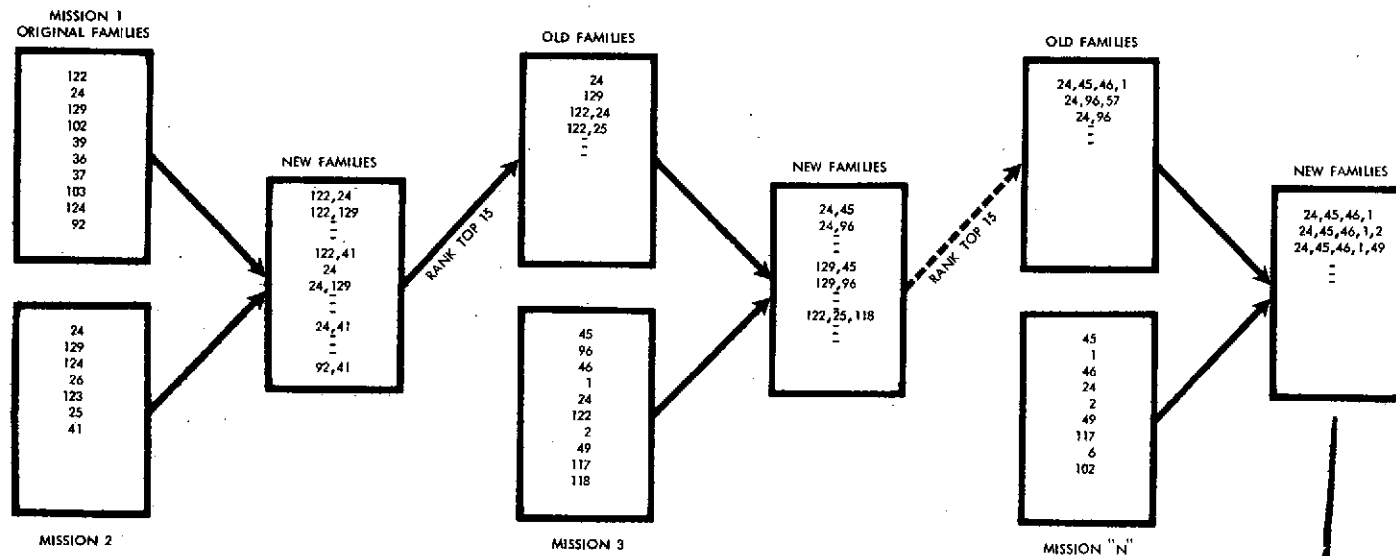
- 1) All possible combinations of mission 1 and mission 2 vehicles are made into individual families which can accomplish the two missions. This is illustrated in the accompanying chart starting at the upper lefthand corner. The resultant table of "New Families" is then ranked according to cost to accomplish both missions and then listed as the "Old Families" as shown on the chart. Only the 15 "best" families are retained to conserve computer storage space and computational time. This is the second major assumption in the algorithm - i.e., that the optimum family will be a derivative of one of the 15 families retained.
- 2) The "Old Families" just created are now combined with the vehicles from mission 3 to create a new set of "New Families" and they are then ranked.
- 3) This process is repeated until all the missions have been included.

The final answer consists of 15 possible families comprised of different vehicles and/or different mission assignment possibilities.

It should be noted that in computing the costs of the families, the program considers such things as sharing R & D costs, learning on unit costs, sharing operational costs, and maintenance of capability if no flights occur during an interval of more than one year, etc. This is discussed further in the following charts.

The assumption of retaining only the 15 "best" families during the matrix reduction, of course, precludes a 100% confidence that the optimum family arrived at is, in fact, the best. However, experience has shown that a very high degree of confidence can be obtained by rerunning the analysis with the missions reordered and/or eliminating stages.

FAMILY SELECTION



FINAL FAMILIES

RANK = 1 COST = .3077086+U4		FAMILY NUMBER = 1					
NUMBER OF VEHICLES = 4		MISSION	FLIGHTS	VEHICLE	STAGE 1	STAGE 2	STAGE 3
VEHICLE	NUMBER	1	2	24	2		
24	13	2	2	24	2		
45	29	3	9	45	3		
46	8	4	5	45	3		
1	2	5	0	45	3		
0	0	6	0	45	3		
		7	0	45	3		
		8	12	45	3		
		9	2	45	3		
		10	1	24	2		
		11	2	45	3		
		12	2	45	3		
		13	2	46	3		
		14	12	45	3		
		15	0	45	3		
		16	7	45	3		

STAGES IN FAMILY 1	
STAGE NO.	FLIGHTS
1	47
2	26
3	389

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COST ESTIMATING RELATIONSHIPS

This and the next two charts summarize the cost estimating relationships used in the program. Wherever possible, costs are input to minimize the dependence of this program on Cost Estimating Relationships (CER). For example, the RDT&E and TFU costs for the structure and engine of a stage along with the RDT&E and TFU costs of a guidance module are input. Vehicle RDT&E costs are based on the RDT&E costs of the component stages and guidance module and a complexity factor (COMFAC) which depends on the number of different engines (DIFFE), the number of different stages (DIFFS) and an input constant (CC1). Interstage unit costs are computed by multiplying the interstage weight by an input constant.

COST ESTIMATING RELATIONSHIPS

RD&E

STRUCTURE (I.E. STAGE LESS ENGINE)	=	INPUT
ENGINE	=	INPUT
GUIDANCE MODULE	=	INPUT
VEHICLE	=	$(1.00 + 0.04 + \text{COMFAC}) (\text{RD\&E}_{\text{STRUCTURE}} + \text{RD\&E}_{\text{ENGINE}} + \text{RD\&E}_{\text{GUIDANCE MODULE}})$

THEORETICAL FIRST UNIT

STRUCTURE	=	INPUT
ENGINE	=	INPUT
GUIDANCE MODULE	=	INPUT
INTERSTAGE	=	CONSTANT (INTERSTAGE WEIGHT)

NOTE : $\text{COMFAC} = \text{CC1} \left[\frac{\text{DIFFE} + \text{DIFFS}}{2} \right] \left(\frac{2}{\text{DIFFE} + \text{DIFFS}} \right)$

COST ESTIMATING RELATIONSHIPS
(continued)

The cost estimating relationships, CERS, used to compute investment costs are summarized on this chart.

COST ESTIMATING RELATIONSHIPS

(Continued)

INVESTMENT COSTS

$$\text{FACILITIES TOOLING AND EQUIPMENT} = 0.03 (W_{\text{STRUCTURE}})^{0.593}$$

$$\begin{aligned} \text{GSE} = & 0.014 (\text{RDT\&E}_{\text{ENGINE}}) + 0.08 (W_{\text{STRUCTURE}})^{0.347} + 0.05 (W_{\text{EMPTY}})^{0.57} \\ & + 0.05 (\text{RDT\&E}_{\text{GUIDANCE MODULE}}) \end{aligned}$$

$$\text{STRUCTURE} = (\text{TFU}_{\text{STRUCTURE}}) (\text{NUMBER})^{\text{RLS}}$$

$$\text{ENGINE} = (\text{TFU}_{\text{ENGINE}}) (\text{NUMBER})^{\text{RLE}}$$

$$\text{PROJECT MANAGEMENT} = 0.08 (\text{TFU}_{\text{STAGE}})$$

$$\text{INITIAL OPERATING SPARES} = 0.10 (\text{INVESTMENT}_{\text{STRUCTURE \& STAGE}})$$

$$\text{SUSTAINING ENGINEERING} = 0.20 (\text{INVESTMENT}_{\text{STRUCTURE \& STAGE}})$$

$$\text{GUIDANCE MODULE} = (\text{NUMBER}) (\text{TFU}_{\text{GUIDANCE MODULE}})$$

$$\text{PROPELLANT COST} = (\text{COST OF PROPELLANT / POUND}) (\text{WT. OF PROPELLANT USED})$$

COST ESTIMATING RELATIONSHIPS
(continued)

Operations costs CER's are summarized in this chart. Note that the factor, FCT, used in computing launch, payload and vehicle integration costs is a step function depending on the average number of flights per year, ANFPY. Maintenance of capability costs, MOC, are based on an input constant, the number of inactive years and the cost for launch, training and sustaining engineering. The cost for delivering the payload and upper stage(s) to the departure orbit is based on an input dollars per pound figure.

COST ESTIMATING RELATIONSHIPS

(Continued)

OPERATIONS COST

- LAUNCH + TRAINING + SUSTAINING ENGINEERING = CONSTANT (0.439 + 0.561 (FCT))
- EQUIPMENT MAINTENANCE = $0.01 (W_{\text{STRUCTURE}})^{0.593}$ (CONSTANT) (NUMBER OF YEARS)
- MOC = (CONSTANT) (NO. INACTIVE YEARS) (LAUNCH + TRAINING + SUSTAINING ENGINEERING COSTS)
- SHUTTLE CHARGES PER FLIGHT = (\$/LB) $(W_{\text{STAGE}} + W_{\text{PAYLOAD}})$

PAYLOAD INTEGRATION = 1.5 (TOTAL NUMBER OF FLIGHTS) (FCT)

VEHICLE INTEGRATION = 1.5 (COMFAC - 1.) (FCT) (NUMBER FLIGHTS)

NOTE: $FCT = ANFPY \left[\frac{(ANFPY-2)(ANFPY-3)(ANFPY-4)}{2(ANFPY)^3} \right]$

STUDY DATA

STAGE DATA SUMMARY

Eight stages were considered in the Task 1 study. The first four shown in this chart are liquid stages and the last four are solids. All of the liquid stages were assumed to have their own integral guidance; whereas, the solid stages required the addition of the input guidance module. An RDT&E costs is shown for each of the stages even though all stages presently exist. This cost reflects the effort required to adapt the stage to the Shuttle.

The data shown in the chart was compiled from existing sources in the literature and informal discussions with NASA personnel. Official NASA data was not provided for this task assignment since it was not essential to meeting the primary objective of this task assignment - i.e., to evaluate the approach.

STAGE DATA SUMMARY

STAGE*	TOTAL WEIGHT	PROPELLANT WEIGHT	SPECIFIC IMPULSE	DIAMETER	LENGTH	NUMBER OF STARTS	RDT&E COST	FIRST UNIT COST	ANNUAL OPERATIONS COST †
AGENA	15003	13561	291.0	5.0	23.0	10	40,000	2.070	8,2000
CENTAUR	34662	30300	444.0	10.0	32.0	10	50,000	5.250	4,720
DELTA	12092	10360	304.0	8.0	19.3	10	40,000	1.440	2,440
TRANSTAGE	27477	23300	302.0	10.0	15.0	10	40,000	3.326	1,640
CASTOR II (TX-354-5)	8771	8208	282.0	4.0	15.0	1	10,000	0.103	4,822
ANTARES II (X-259)	3216	2578	282.0	4.0	5.0	1	10,000	0.080	4,822
BURNER II- (TE-M364-2)	1780	1440	290.0	5.4	5.8	1	10,000	0.500	4,822
SECOND STAGE BURNER II A (TE-M-442)	800	524	278.0	5.4	3.0	1	10,000	0.210	4,822

*UNITS ARE: POUNDS, FEET, SECONDS, AND MILLIONS OF DOLLARS

† LAUNCH + TRAINING + SUSTAINING ENGINEERING

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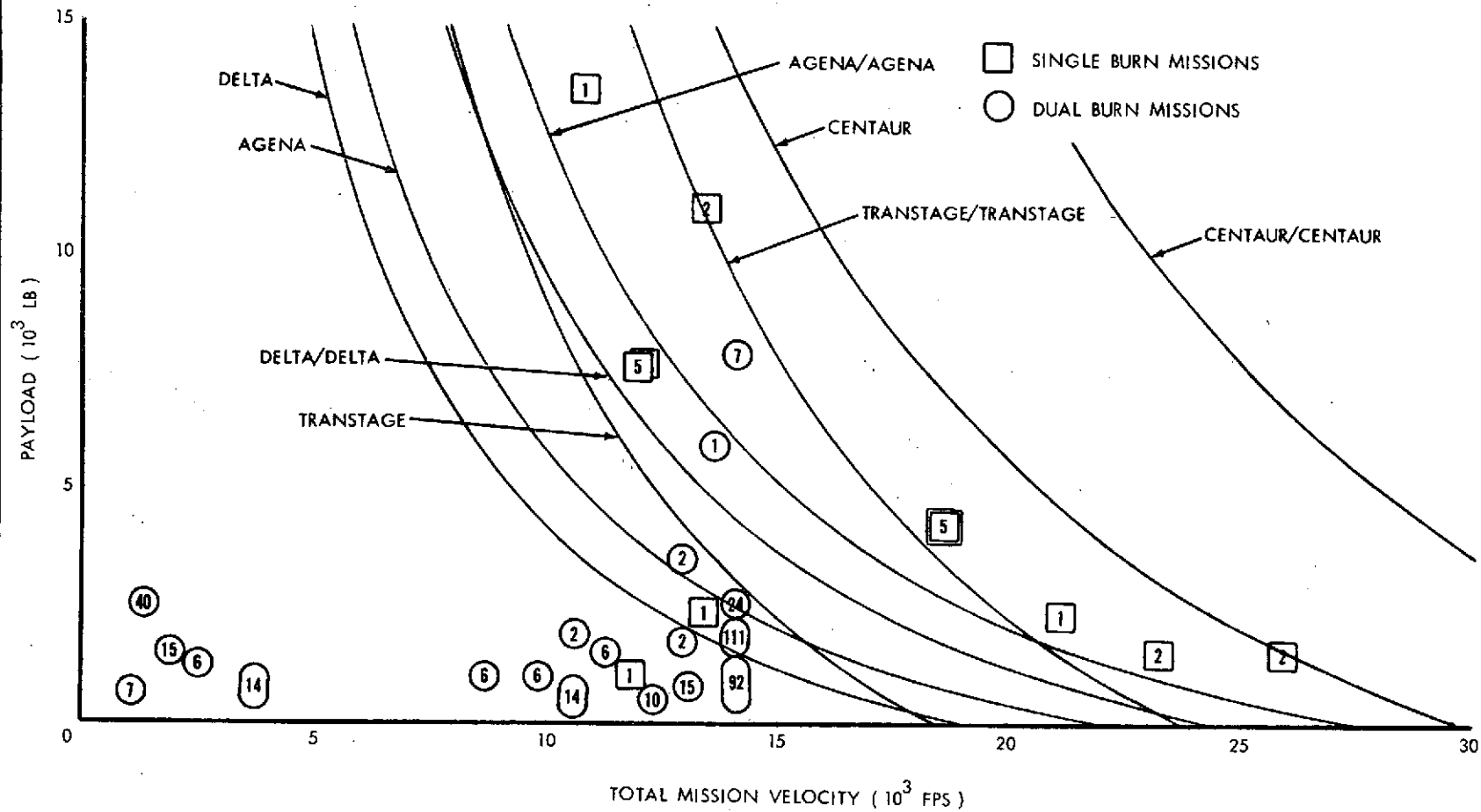


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52 MISSIONS MODEL

Several mission models were evaluated in the study. The first was comprised of 52 different missions. Each mission consisted of one or more flights and the total program had 400 flights. This chart shows the payload and total velocity for each mission as well as the number of flights for that mission. Missions of a single burn are depicted as a square and those of a dual burn are shown as a circle. The numbers within the squares and circles represent the number of times each mission is flown. Also shown on the chart are the performance capabilities of some typical vehicles. Although not shown, each mission was also characterized by the year of the first flight and the year of the last flight, and the total coast time associated with each burn.

52 MISSION MODEL



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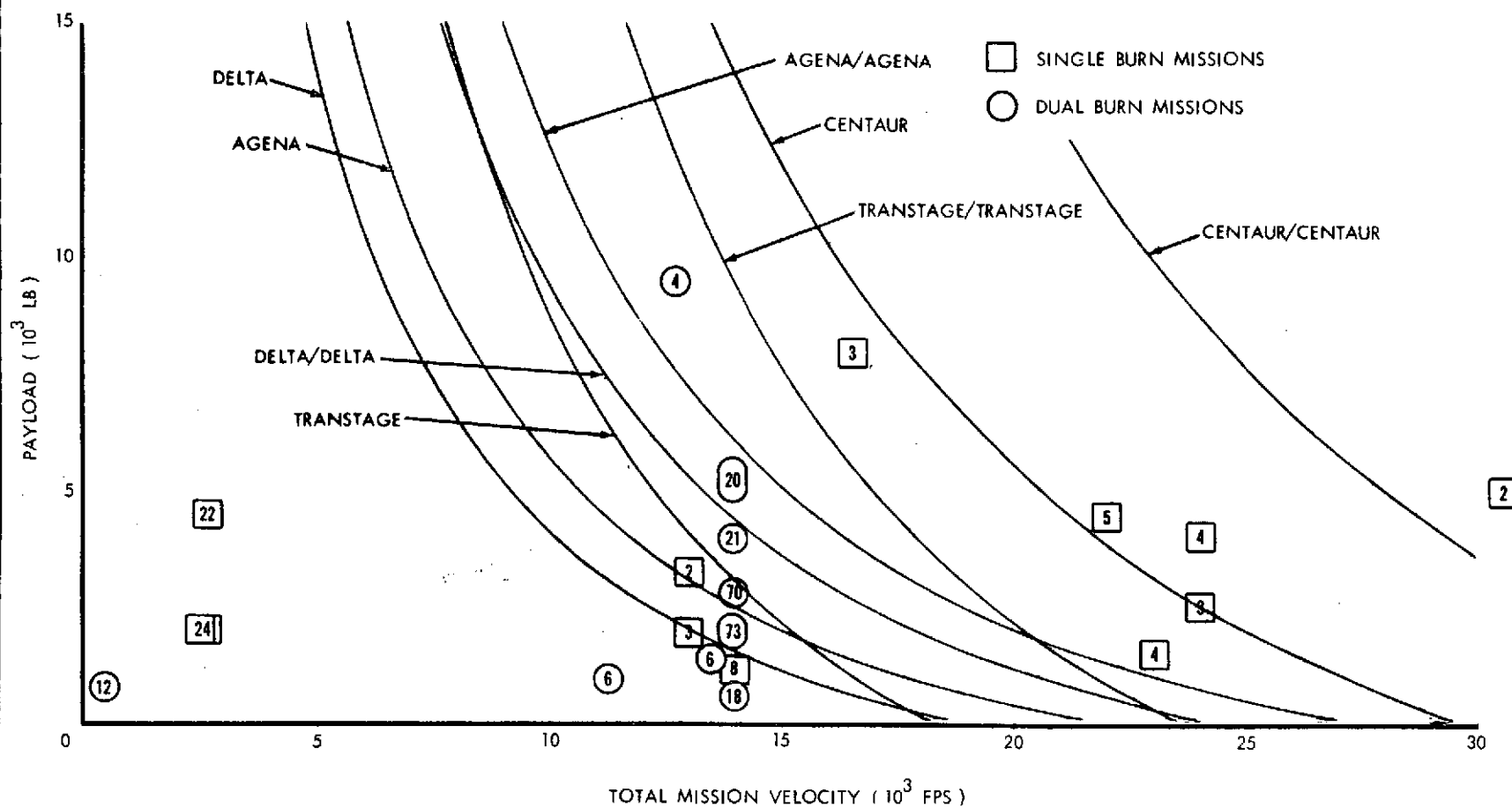


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24 MISSIONS MODEL

The missions shown on this chart correspond to the mission model used for the current Space Tug Systems Studies. There are 24 missions of which eight are synchronous orbit missions, eight are for missions to other orbits and eight are for planetary missions. The performance capabilities of some typical vehicle combinations are also shown on this chart.

24 MISSION MODEL



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STUDY RESULTS

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52 MISSIONS - 400 FLIGHTS

This chart presents the three best families to accomplish this mission model for three different shuttle transportation-to-orbit costs (0, 150 and 225 dollars/pound). If shuttle costs are independent of the weight delivered to orbit (e.g. 0.\$/lb) then the best family is a simple one requiring 483 Delta and 26 Centaur stages. However, as transportation to orbit costs increase it becomes more attractive to add an additional stage - in this case the Burner II. The results show that for a given transportation-to-orbit cost there is not much difference in cost between the number 1 and number 3 families. Thus, keeping "extra" stages in the family can be done for growth or contingency reasons at little penalty.

In all the families the Centaur was selected in preference to the Transtage. This is attributable to the fact that several of the missions could not be accomplished by a Dual Transtage (2 stages) and retaining both Centaur and Transtage was not cost effective.

52 MISSIONS - 400 FLIGHTS

FAMILY	TRANSPORTATION TO ORBIT COST = \$0 / LB			FAMILY	TRANSPORTATION TO ORBIT COST = \$150 / LB			FAMILY	TRANSPORTATION TO ORBIT COST = \$225 / LB		
	PROGRAM COST (BILLION \$)	ASSIGNED MISSIONS	TOTAL NO. FLIGHTS		PROGRAM COST (BILLION \$)	ASSIGNED MISSIONS	TOTAL NO. FLIGHTS		PROGRAM COST (BILLION \$)	ASSIGNED MISSIONS	TOTAL NO. FLIGHTS
<u>NUMBER 1</u>	1.994			<u>NUMBER 1</u>	2.961			<u>NUMBER 1</u>	3.433		
DELTA		29	265	DELTA		29	265	BURNER II / BURNER II		2	34
DELTA / DELTA		10	109	DELTA / DELTA		10	109	DELTA		27	231
CENTAUR		13	26	CENTAUR		13	26	DELTA / DELTA		8	72
<u>NUMBER 2</u>	2.019			<u>NUMBER 2</u>	2.974			DELTA / BURNER II		2	37
ANTARES II / ANTARES II		1	6	BURNER II / BURNER II		2	34	CENTAUR		13	34
DELTA		28	259	DELTA		27	231	<u>NUMBER 2</u>	3.445		
DELTA / DELTA		10	109	DELTA / DELTA		8	72	DELTA		29	265
CENTAUR		13	26	DELTA / BURNER II		2	37	DELTA / DELTA		10	109
<u>NUMBER 3</u>	2.020			CENTAUR		13	26	CENTAUR		13	26
TE-M-442 / TE-M-442				<u>NUMBER 3</u>	2.986			<u>NUMBER 3</u>	3.446		
OR				TE-M-442 / TE-M-442		1	6	TE-M-442 / TE-M-442		1	6
CASTOR / CASTOR		1	6	DELTA		28	259	BURNER II / BURNER II		26	34
DELTA		28	259	DELTA / DELTA		10	109	DELTA		26	225
DELTA / DELTA		10	106	CENTAUR		13	26	DELTA / DELTA		8	72
CENTAUR		13	26					DELTA / BURNER II		2	37
								CENTAUR		13	26

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22 MISSIONS - 298 FLIGHTS

In the 24 mission model shown earlier there were several planetary flights which could not be accomplished without an orbital assembly of stages (to avoid exceeding a length limit); therefore, these missions were excluded for the purposes of this study. The format of the data is the same as the previous chart. The trends observed are similar to those of the previous chart in that:

- 1) As transportation costs increase, the optimum number of different stages in the optimum family increases; and
- 2) there is only a small cost penalty involved in not selecting the number 1 family over the 2nd or 3rd ranked families.

It is interesting to note that if transportation-to-orbit costs become a factor, the optimum families include both the Delta and Agena stages - two stages which are very similar in size and technology. Again the Centaur was selected in lieu of the Transtage because there were missions which can be accomplished by Centaur, but not by the Dual Transtage.

22 MISSIONS - 298 FLIGHTS

FAMILY	TRANSPORTATION TO ORBIT COST = \$0 / LB			FAMILY	TRANSPORTATION TO ORBIT COST = \$150 / LB			FAMILY	TRANSPORTATION TO ORBIT COST = \$225 / LB		
	PROGRAM COST (BILLION \$)	ASSIGNED MISSIONS	TOTAL NO. FLIGHTS		PROGRAM COST (BILLION \$)	ASSIGNED MISSIONS	TOTAL NO. FLIGHTS		PROGRAM COST (BILLION \$)	ASSIGNED MISSIONS	TOTAL NO. FLIGHTS
NUMBER 1	1.785			NUMBER 1	2.763			NUMBER 1	3.357		
CASTOR		6	66	ANTARES II		3	46	ANTARES II / ANTARES II		3	46
CASTOR / CASTOR		2	5	DELTA		6	47	DELTA		6	47
DELTA		2	24	DELTA / DELTA		3	93	DELTA / DELTA		2	91
DELTA / DELTA		6	164	AGENA		4	73	AGENA		4	73
CENTAUR		6	34	AGENA / AGENA		1	14	AGENA / AGENA		1	14
CENTAUR / DELTA		1	5	AGENA / DELTA		1	6	AGENA / ANTARES II		1	2
				CENTAUR		4	14	AGENA / DELTA		1	6
				CENTAUR / DELTA		1	5	CENTAUR		4	14
NUMBER 2	1.786			NUMBER 2	2.766			CENTAUR / DELTA		1	5
ANTARES II		5	58	DELTA		9	93	NUMBER 2	3.361		
DELTA		4	35	DELTA / DELTA		3	93	CASTOR		3	46
DELTA / DELTA		4	139	AGENA		4	73	CASTOR / CASTOR		2	5
DELTA / ANTARES II		3	27	AGENA / AGENA		1	14	DELTA		5	44
CENTAUR		6	34	AGENA / DELTA		1	6	DELTA / DELTA		2	91
CENTAUR / DELTA		1	5	CENTAUR		4	14	AGENA		4	73
				CENTAUR / DELTA		1	5	AGENA / AGENA		1	14
NUMBER 3	1.798							AGENA / DELTA		1	6
ANTARES II		5	58					CENTAUR		4	14
CASTOR / CASTOR		1	2					CENTAUR / DELTA		1	5
DELTA		4	35								
DELTA / DELTA		3	137					NUMBER 3	3.367		
DELTA / ANTARES II		3	27					ANTARES II		3	46
CENTAUR		6	34					CASTOR / CASTOR		1	2
CENTAUR / DELTA		1	5					DELTA		6	47
								DELTA / DELTA		2	91
								AGENA		4	73
								AGENA / AGENA		1	14
								AGENA / DELTA		1	6
								CENTAUR		4	14
								CENTAUR / DELTA		1	5

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19 MISSIONS - 283 FLIGHTS

By way of illustrating how the program can be used to evaluate alternative stages or technologies the previous model was altered to enable all missions to be accomplished by the Dual Transtage. Then this altered mission model was run with all eight stages and then again with the Transtage omitted (to force the selection of Centaur). The results are shown in this chart which compares the Centaur and Transtage families. The results show that if transportation cost is not a factor, then the Transtage family should be about 66 million dollars cheaper - assuming that Centaur is not used for multi-payload deployment. However, as transportation costs increase the difference disappears completely and the two families are a toss-up.

19 MISSIONS - 283 FLIGHTS

FAMILY	TRANSPORTATION TO ORBIT COST = \$0 / LB			FAMILY	TRANSPORTATION TO ORBIT COST = \$150 / LB			FAMILY	TRANSPORTATION TO ORBIT COST = \$225 / LB		
	PROGRAM COST (BILLION \$)	ASSIGNED MISSIONS	TOTAL NO. FLIGHTS		PROGRAM COST (BILLION \$)	ASSIGNED MISSIONS	TOTAL NO. FLIGHTS		PROGRAM COST (BILLION \$)	ASSIGNED MISSIONS	TOTAL NO. FLIGHTS
<u>TRANSTAGE FAMILY</u>	1.630			<u>TRANSTAGE FAMILY</u>	2.482			<u>TRANSTAGE FAMILY</u>	2.867		
DELTA		9	93	DELTA		9	93	ANTARES II		4	52
DELTA / DELTA		7	166	DELTA / DELTA		3	93	DELTA		5	41
TRANSTAGE / TRANSTAGE		1	4	AGENA		4	73	DELTA / DELTA		2	91
TRANSTAGE / DELTA		2	20	AGENA / AGENA		1	14	AGENA		4	73
				AGENA / DELTA		1	6	AGENA / AGENA		1	14
<u>CENTAUR FAMILY</u>	1.696			TRANSTAGE / AGENA		1	4	AGENA / ANTARES II		1	2
DELTA	(ACOST = \$66M)	9	93	<u>CENTAUR FAMILY</u>	2.506			AGENA / DELTA		1	6
DELTA / DELTA		3	93	CASTOR	(ACOST = \$24M)	3	4	TRANSTAGE / AGENA		1	4
AGENA		4	73	CASTOR / CASTOR		2	5	<u>CENTAUR FAMILY</u>	2.867		
AGENA / AGENA		2	20	DELTA		5	44	CASTOR	(ACOST = \$0M)	6	66
CENTAUR		1	4	DELTA / DELTA		2	91	CASTOR / CASTOR		2	5
				AGENA		4	73	DELTA		2	24
				AGENA / AGENA		1	14	DELTA / DELTA		2	91
				AGENA / DELTA		1	6	AGENA		4	73
				CENTAUR		1	4	AGENA / AGENA		1	14
								AGENA / DELTA		1	6
								CENTAUR		1	4

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CONCLUSIONS

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CONCLUSION

1. The program can be used to select a family of expendable vehicles which, if not the true optimum, will not be more than 2% more costly than the "true" optimum.
2. Computation time (and cost) are very reasonable (approximately 10-20 seconds/case).
3. The program can be useful in evaluating alternative stages and/or alternative mission models.
4. Customer supplied cost data is essential to providing answers which can be used with confidence.
5. The program should be modified to enable consideration of reusable stages.

CONCLUSIONS

- PROGRAM CAN FIND THE OPTIMUM FAMILY OF EXPENDABLE VEHICLES.
- COMPUTATION TIME (10 - 20 SECONDS PER CASE) AND COST ARE VERY REASONABLE.
- THE APPROACH CAN BE USEFUL IN TRADING OFF STAGE ALTERNATIVES FOR DIFFERENT MISSION MODELS.
- CUSTOMER SUPPLIED DATA IS ESSENTIAL TO PROVIDING ANSWERS WHICH CAN BE USED WITH CONFIDENCE.
- THE PROGRAM SHOULD BE MODIFIED TO ENABLE CONSIDERATION OF REUSABLE STAGES.

